OPTIMIZATION OF ABRASIVE MACHINING OF DUCTILE CAST IRON USING WATER BASED ZnO NANOPARTICLES: A SUPPORT VECTOR MACHINE APPROACH

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ABSTRACT

This project presents the optimization of abrasive machining of ductile cast iron using water based ZnO nanoparticles. This study were carried out to investigate the performance of grinding machine of ductile cast iron based on response surface methodology (RSM), to develop optimization model for grinding parameters using support vector machine (SVM) and to investigate the effect of water based ZnO nanoparticles in grinding machine. Analysis of variance has been carried out to check the adequacy of the experimental results. The mathematical modeling has been developed using response surface methodology to investigate the performance of grinding machine of ductile cast iron. The optimization model of grinding parameter was developed and the effect of water based ZnO nanoparticles was investigated. From the obtained results, the optimum parameter for grinding model is 30m/min table speed and 40µm depth of cut. The quality of product was determined by output criteria that are minimum temperature rise, minimum surface roughness and maximum material removal rate. Based on prediction data from RSM shows that 2^{nd} order gives the good performance of grinding machine with the significant p-value of analysis of variance that is below than 0.05 and support with R-square value nearly 0.99. Based on the support vector machine (SVM) results, high depth of cut and low table speed gives high quality of product. It shows that SVM result is acceptable since the results was the same as obtained results from response surface methodology (RSM) and can be used to optimize the grinding machine. The results also shows that water based ZnO nanoparticles as a nanocoolant give impact to the temperature rise. It gives temperature rise almost zero compared to conventional coolant. High temperature rise will affect the surface roughness of product, so that it is very efficiency to choose water based ZnOnano particles as a nanocoolant. As the conclusion, the results obtained from this project can be used to optimize the precision grinding machine to get high quality of product using water based ZnO nanoparticles.

ABSTRAK

Tesis ini adalah tentang mengoptimumkan parameter pemipisan besi tuang mulur dengan menggunakan air yang berdasarkan nanopartikel ZnO. Kajian telah dibuat untuk menyiasat prestasi pemipisan mesin besi tuang mulur berdasarkan kaedah respons permukaan (RSM), untuk membangunkan model pengoptimuman untuk parameter mengisar menggunakan pendekatan sokongan vector mesin (SVM) dan untuk mengkaji kesan air berdasarkan nanopartikel ZnO dalam pemipisan mesin. Analisis varians telah dilakukan bagi memastikan kesahihan data yang diperolehi. Matematik model telah dibuat dan kesan air berdasarkan nanopartikel ZnO. Daripada ujikaji tersebut, optimum parameter bagi model pemipisan adalah 30m/min kelajuan meja dan 40μm kedalaman potongan membolehkan mempunyai kualiti produk yang terbaik. Kualiti produk telah ditentukan oleh beberapa kriteria. Kriteria tersebut ialah kenaikan suhu minimum, kekasaran permukaan minimum dan kadar pemipisan bahan maximum. Berdasarkan data ramalan daripada RSM menunjukkan bahawa persamaan tahap kedua memberikan prestasi mesin pemipisan yang baik dengan nilai p dibawah 0.05 dan sokongan R kuasa dua hampir 0.99. Berdasarkan keputusan mesin sokongan vektor, kedalaman pemotongan yang tinggi dan kelajuan meja yang rendah akan menghasilkan produk yang bermutu tinggi. Ini telah menunjukkan bahawa SVM boleh diterima pakai disebabkan keputusan yang diperolehi sama dengan keputusan RSM dan boleh digunakan untuk mengoptimumkan mesin pemipisan. Keputusan yang diperolehi juga menunjukkan bahawa air yang berdasarkan nanopartikel ZnO telah memberikan kesan terhadap kenaikan suhubahan. Kenaikan suhu yang tinggi akan menyebabkan kerosakan pada produk, oleh itu dengan menggunakan air yang berdasarkan nanopartikel ZnO adalah memuaskan. Sebagai kesimpulan, keputusan keseluruhan yang diperolehi daripada projek ini boleh diguna pakai untuk mengoptimumkan mesin pemipisan untuk mendapatkan hasil produk yang berkualiti tinggi.

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ϕ	volume concentration in percentages (%)
ω	weight in percentages (%)
ρ_w	density of water
ρ_p	density of nanoparticles
ΔV	amount of distilled water
V_1	volume nanoparticles
ϕ_1	old concentration
ϕ_2	new concentration

LIST OF ABBREVIATIONS

TS	Table speed
DOC	Depth of cut
T	Temperature rise
R_a	Arithmetic average surface roughness
MRR	Material removal rate

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Nowadays, the grinding process is widely used especially in mechanical engineering field. Grinding is a material removal and surface generation process used to shape and finish components made of metals and other materials (Shen et al., 2008). The precision and surface finish obtained through grinding can be up to ten times better than with either turning or milling. Temperature also can give effect to workpiece. Such high temperatures can cause thermal damage to the workpiece, which affects the workpiece quality and limits the process productivity (Malkin and Guo, 2007). The input parameters (types of wheel, types of coolant and depth of cut) can improve the quality of the product. The output parameters in order to choose the best quality of product produced that are surface roughness, tool wear, thermal temperature and material removal rate (MRR).

Coolant is the liquids use to keep surface of the work piece cool. It also can enhance cutting process such as quality of the product. Nanofluids have the potential to be next generation of coolants due to their significantly higher thermal conductivities (Zhang et al., 2009). The nanofluids with various concentrations using grinding machine to optimize the grinding machine of ductile cast iron when using water based ZnO nanoparticles as a coolant. The experiment on conventional coolant in order to compare the result with water based ZnO nanoparticles as a coolant. Ductile cast iron frequently referred to as nodular or spheroid graphite iron is a recent member of the family of cast irons. It contains spheroid graphite in the as cast condition, through the addition of nucleating agents such as cerium or magnesium to the liquid iron. Ductile cast iron is essentially a family of materials with a wide verity of properties which are satisfactory for different engineering requirements. Currently, the ductile cast iron usually in many automotive components, where strength needs surpass that of aluminum but do not necessarily requires steel. Furthermore, ductile cast iron also can be found as a pipe where ductile cast iron is much stronger than other pipe, requires less support and provide greater flow. Therefore ductile cast iron is considered as a workpiece material.

1.2 PROBLEM STATEMENT

The quality of surface finish is an significant requirement for many grinded workpieces. The choice of optimized cutting parameters is very important for controlling the required surface quality. Grinding is the most precise machining process that is used to improve surface roughness of the work piece. It has tactile contact where when it touches the surface of the object can feel the surface roughness, waviness, texture and other scratches. Besides that the effect of coolant very important because to reduce surface cracking and subsurface damage. Nanofluids are formed by dispersing nanoparticles in base fluids such as water. It has been reported that the thermal conductivities of nanofluids increase dramatically due to the high thermal conductivity of solid particles suspended in the heat-transfer fluid (Chen et al., 2008). The suitable parameters needs because it can affect the surface texture been rougher, and the surface is not shining. The parameters that should be optimized are types of coolant, table speed and depth of cut. The results of experiment must consider in different perspective of a parameter to obtain accurate results. The manufacturing industry will have an alternative method in saving the cost of production and increasing production. By determining the optimum parameters for abrasive machine, the industry could use the method to optimize the parameters such as depth of cut, table speed and types of coolant. In normal situation, workers who handle an abrasive machine must have specific experience and skills. This study helps the non-experience worker to handle the abrasive machine in the obtaining optimum parameters used, on the other hands, by using nanofluid as a coolant in order to get the best-quality surface roughness and good dimension of product. Thus, further study is needed in order to accomplish the vision and within given the limitation.

1.3 OBJECTIVES OF PROJECT

The objectives of this project are as follows:

1) To investigate the performance of grinding machine of ductile cast iron based on response surface method.
2) To develop optimization model for grinding parameters using support vector machine technique.
3) To investigate the effect of water based ZnO nanoparticles in the precision surface grinding.

1.4 SCOPES OF PROJECT

This study focus on optimization of abrasive machining of ductile cast iron using water based ZnO nanoparticles. Therefore, the scopes of the project are needed as a guide in order to achieve the objectives. There are several scopes as follows:

1) Design the experiment for grinding process and preparation of 0.1% water based ZnO nanoparticles.
2) Perform experiment on grinding machine utilizing abrasive grinding wheel, water based ZnO and ductile cast iron.
3) Perform surface roughness and material removal rate analysis.
4) Analysis data using response surface methodology and support vector machine approach.

1.5 ORGANIZATION OF PROJECT

Chapter 2 is about the literature review that will be focused on recent past studies related to the effect of grinding process parameters. Chapter 3 presents the methodology that will be conducted for this process by the design of experiment, setup of machine, selection of parameters, experiment layout and others. Chapter 4 is about the MRR, surface roughness and G–ratio when increasing the depth of cut, types of wheel and grinding direction in order to get the best and optimum parameters should be used to get the best product. Chapter 5 is about the conclusion of this project from all the experiment conducted. This chapter also will summarize the findings and recommendation for the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter briefly explains about the grinding, ductile cast iron, nanoparticles, response surface method and support vector machine. Grinding is widely used as the finishing machining process for components that require smooth surfaces and precise tolerances. A large volume of grinding fluid is most commonly used to flood the grinding zone, hoping to achieve tangible productivity targets while often neglecting the seemingly less tangible environmental and safety hazards. In addition, the inherent high cost of disposal or recycling of the grinding fluid becomes another major concern, especially as the environmental regulations get stricter. Minimizing the quantity of cutting fluid is desirable in grinding (Shen et al., 2008). Grinding is a very important finishing process in the automotive industry and often requires close tolerance and high surface finish. Material removal rates in grinding are limited because of chatter and other problems such as thermal damage (Walsh et al., 2002).

In material removal operations, the role of grinding process is indispensable, especially in finishing operations that demand close tolerances, for application such as bearings, pin joints, shafts, etc. Grinding is an abrasive process, where the workpiece is forced against the grinding wheel. As a result of abrasive wear, the process generates chips that are removed from the workpiece surface (Shen et al., 2008). During grinding, most of the input energy is converted into heat, causing high temperatures particularly at the wheel-workpiece interface (the small portion of the grinding wheel actually in contact with the workpiece). Such high temperatures can cause thermal damage to the workpiece, which affects the workpiece quality and limits the process productivity

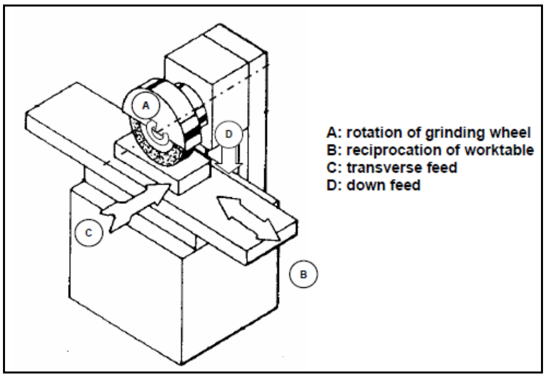
(Malkin et al., 2007). Grinding wheel wear is also a major concern. To control heat and wheel wear or to improve the grinding performance, a heavy amount of grinding fluids (coolant) is used. The conventional cutting fluids used in grinding are considered a problem, as these substances can cause a large amount of mist, which is environmentally challenging and is expensive (Silva et al., 2005).

The machining processes have an important place in the traditional production industry. Cost-effectiveness of all machining processes has been eagerly investigated. This is mainly affected selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and workpiece material. The selection of optimum machining parameters will result in longer tool life, better surface finish and higher material removal rate (Cakir, 2007). During machining process, friction between workpiece-cutting tool and cutting tool-chip interfaces cause high temperature on cutting tool. The effect of this generated heat decreases tool life, increases surface roughness and decreases the dimensional sensitiveness of work material. This case is more important when machining of difficult-to-cut materials, when more heat would be observed. Various methods have been reported to protect cutting tool from the generated heat. Choosing coated cutting tools are an expensive alternative, and generally, it is a suitable approach for machining some materials such as titanium alloys, heat resistance alloys (Cakir, 2007).

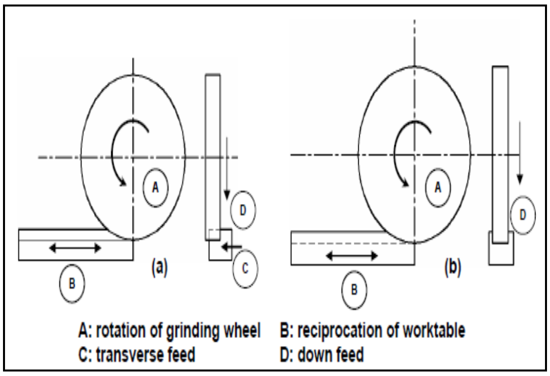
2.2 TYPES OF GRINDING MACHINE

There are many type of grinding machine use to obtain high accuracy along with high class of surface finish on the workpiece. Conventional grinding machines can be broadly classified as surface grinding machine, cylindrical grinding machine, internal grinding machine, and tool and cutter grinding machine.

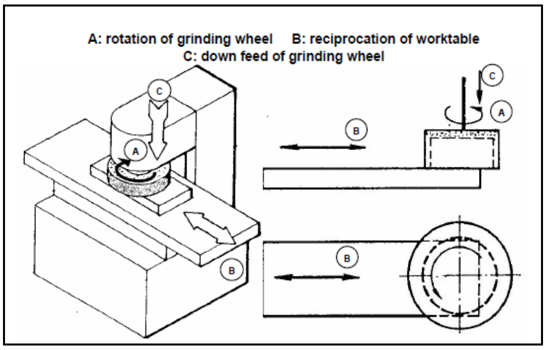
Surface grinding Machine: This machine may be similar to a milling machine used to grind flat surface. However, some types of surface grinders are also capable of producing contour surface with formed grinding wheel. There are four different types of surface grinding machines. Figure 2.1(a) shows this machine with various motions required for grinding action. A disc type grinding wheel performs the grinding action with its peripheral surface. Figure 2.1(b) shows that both traverse and plunge grinding can be carried out.



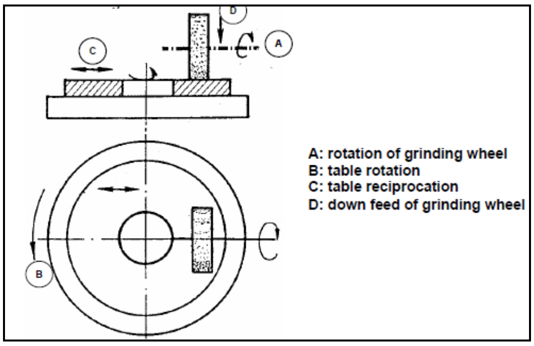
(a) Horizontal spindle reciprocating table



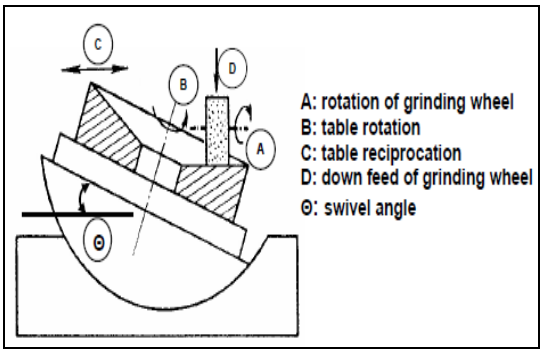
(b) Surface grinding



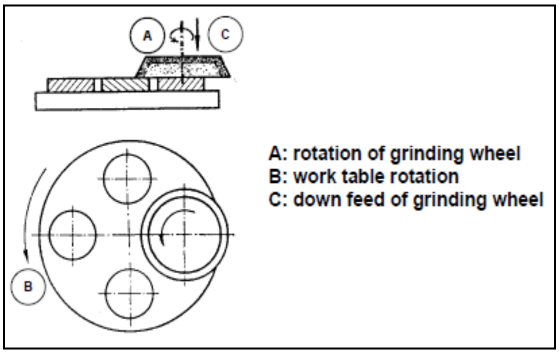
(c) Vertical spindle reciprocating table



(d) Horinzontal spindle rotary table



(e) Horinzontal spindle tapered surface



(f) Vertical spindle rotary table

Figure 2.1: Various types of grinding machine.

Figure 2.1(c) shows that the grinding operation is similar to that of face milling on the vertical milling machine and shows that in this machine a cup shaped wheel grind the workpiece over its full width using end face of the wheel. This bring more grits in action at the same time and consequently a higher material removal rate (MRR) may be attained than for grinding with a peripheral wheel. The principal of this machine is similar as that for facing on the lathe. This machine has a limitation in accommodation of workpiece and therefore does not have wide spread use. However, by swiveling the worktable, concave or convex or tapered surface can be produced on individual part as illustrated in Figure 2.1(d) and 2.(e). This machine is only suitable for small size of workpieces but in large quantities. This primarily production type machine often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table as shows in Figure 2.1(f).

Creep Feed Grinding Machine: This machine enables single pass grinding of a surface with a larger down feed but slower table speed than adopted for multi-pass conventional surface grinding. This machine is characterized by high stiffness, high spindle power, recirculating ball screw drive for table movement and adequate supply of grinding fluid.

High Efficiency Deep Grinding Machine: The concept of single pass deep grinding at a table speed much higher than what is possible in a creep feed grinder has been technically realized in this machine. This has been made possible mainly through significant increase of wheel speed in this new generation grinding machine.

Cylindrical Grinding Machine: This machine is used to produce external cylindrical surface. The surfaces may be straight, tapered, steps or profiled. There are three different types of the cylindrical grinding machines. Figure 2.2 illustrates schematically plain center type cylindrical grinder machine and various motions required for grinding action. The machine is similar to a centre lathe in many respects. The workpiece is held between head stock and tailstock centres. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Figure 2.3. Universal cylindrical grinder is similar to a plain cylindrical one except that it is more versatile. In addition to small worktable swivel, this machine provides large swivel of head stock, wheel head slide and wheel head mount on the wheel head slide. This allows grinding of any taper on the workpiece. Universal grinder is also equipped with an additional head for internal grinding.

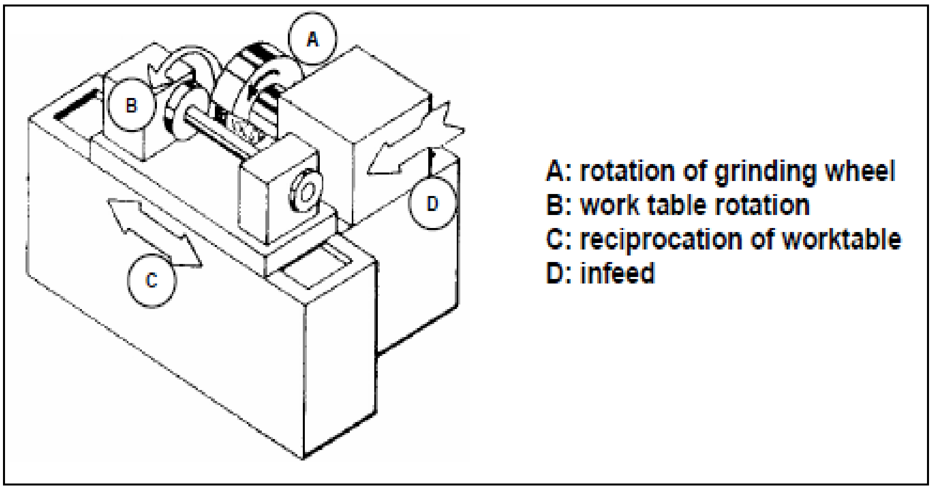


Figure 2.2: Plain center type cylindrical grinder machine

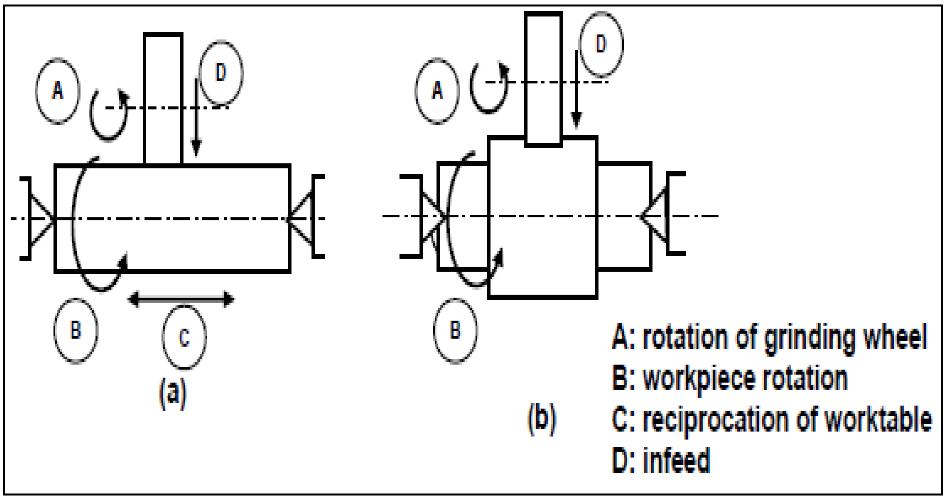


Figure 2.3: Cylindrical (a) Traverse grinding (b) Plunge grinding

Schematic illustration of important features of this machine is shown in Figure 2.4. External centreless grinder is grinding machine is a production machine in which outside diameter of the workpiece is ground. The workpiece is not held between centres but by a work support blade. It is rotated by a regulating wheel and ground by the grinding wheel. In a through-feed center less grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the workpiece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel, and the workpiece is fed longitudinally as shown in Figure 2.5.

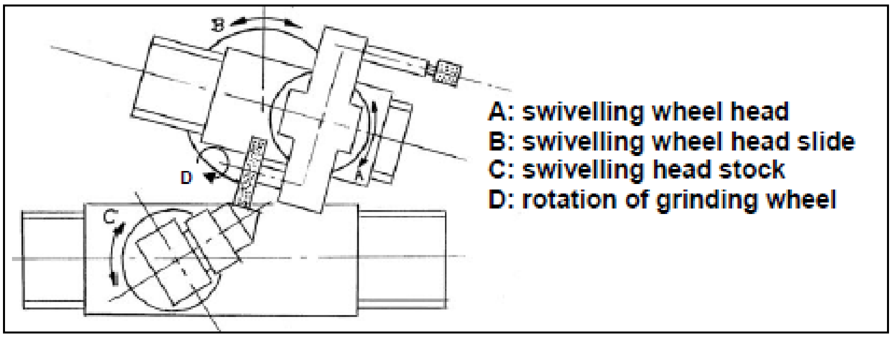


Figure 2.4: Important features of universal cylindrical grinding machine.

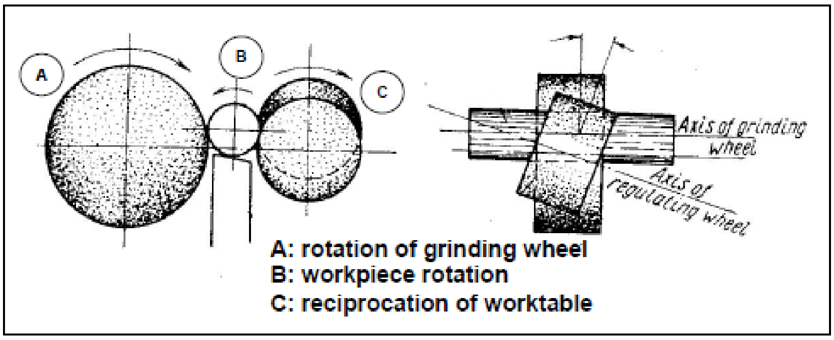


Figure 2.5: Center less through fees grinding

Parts with variable diameter can be ground by Center less in feed grinding as shown in Figure 2.6 (a). The operation is similar to plunge grinding with cylindrical grinder. End feed grinding shown in Figure 2.6 (b) is used for workpiece with tapered surface. The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the workpiece.

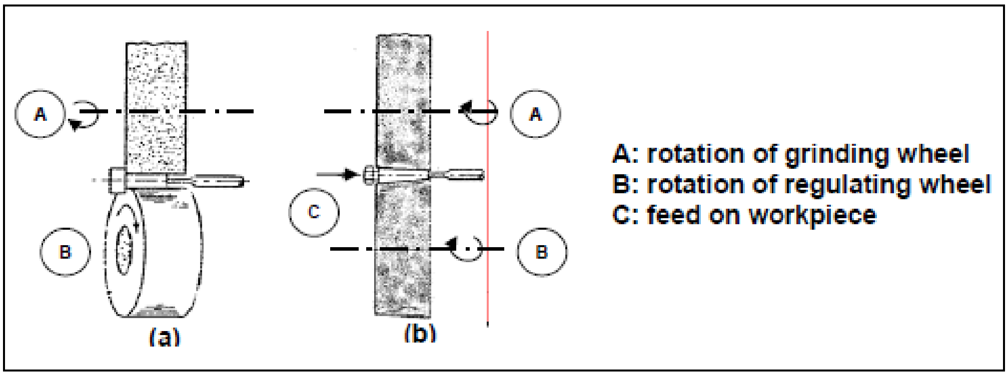


Figure 2.6: Center less (a) In feed; (b) End feed grinding

Internal Grinding Machine: This machine is used to produce internal cylindrical surface. The surface may be straight, tapered, grooved or profiled. Broadly there are three different types of internal grinding machine as follows:

Figure 2.7(a) illustrates schematically chucking type internal grinder machine and various motions required for grinding action. The workpiece is usually mounted in a chuck. A magnetic face plate can also be used. A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out in this machine as shown in Figure 2.7(b). Planetary internal grinder is used where the workpiece is of irregular shape and cannot be rotated conveniently as shown in Figure 2.8. In this machine the workpiece does not rotate. Instead, the grinding wheel orbits the axis of the hole in the workpiece.

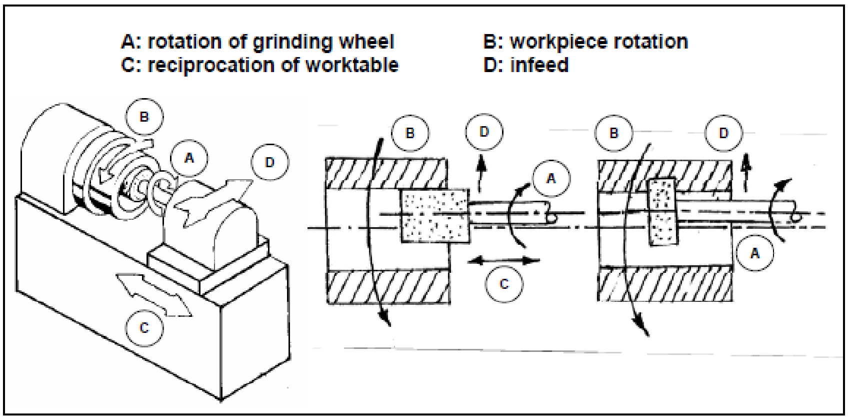


Figure 2.7: (a) Internal Center less grinder (b) Internal (traverse grinding and plunge grinding)

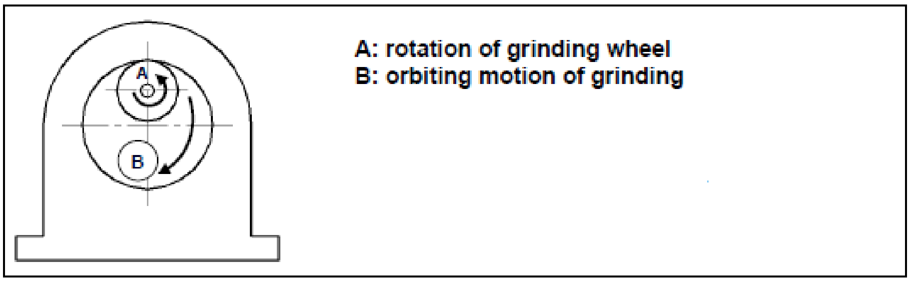


Figure 2.8: Internal grinding in planetary grinder

Center less internal grinder machine is used for grinding cylindrical and tapered holes in cylindrical parts. The workpiece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel as illustrated in Figure 2.9.

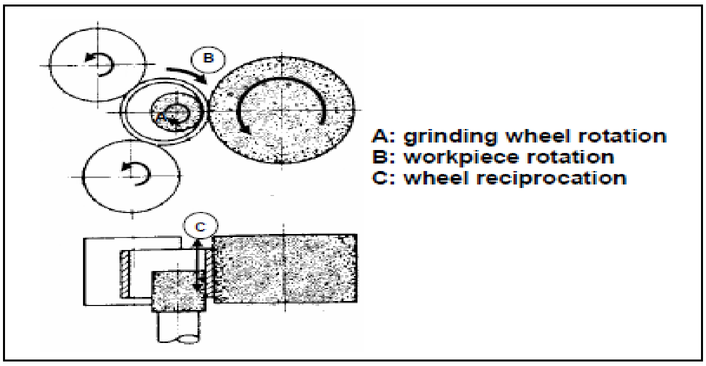


Figure 2.9: Internal center less grinding

Tool and Cutter Grinder Machine: Tool grinding may be divided into two subgroups: tool manufacturing and tool resharpening. There are many types of tool and cutter grinding machine to meet these requirements. Simple single point tools are occasionally sharpened by hand on bench or pedestal grinder. However, tools and cutters with complex geometry like milling cutter, drills, reamers and hobs require sophisticated grinding machine commonly known as universal tool and cutter grinder. Present trend is to use tool and cutter grinder equipped with CNC to grind tool angles, concentricity, cutting edges and dimensional size with high precision.

2.3 SELECTION OF PROCESS PARAMETERS

The productivity, accuracy and cost of grinding processes depend to a considerable extent on the correct choice of process parameters, as the advantages of a good machine and a correct wheel can be lost by operating them under unfavorable conditions. The wheels used in precision grinding operations are normally not self-dressing, wheel wear in grinding is quite small and the cutting efficiency tends to gradually decrease. This means that the wheels should be dressed periodically to restore cutting efficiency and accuracy. Since considerable time and wheel wear is involved in dressing, it is necessary to optimize conditions in such a way as to maximize the period between dressings. These factors that lead to frequent dressings:

Loss of Cutting Efficiency: The cutting efficiency of a wheel is its ability to remove material at a sufficiently fast rate without causing problems of burns, cracks or excessive deflections. The cutting efficiency of a wheel is maintained by the process of abrasive fracture and exposure of fresh cutting edges. Rapid loss of cutting efficiency due to wheel glazing can be combated by increasing the severity of the operation, i.e. by increasing the feeds, depth-of-cut, etc. In extreme cases it may be necessary to use a softer wheel and simultaneously use a coarser grit size if the finish is not a criterion. Quite often, loss of cutting efficiency is accompanied by the appearance of chatter marks on the job surface, after grinding a few pieces. This is sometimes due to a hard wheel. However, the presence of chatter marks immediately after dressing indicates that the wheel is not balanced properly.

Loss of Form and Accuracy: When grinding profiled jobs, the wheel is dressed to the required form. This form is gradually distorted due to uneven wear and necessitates redressing. In such cases, the frequency of dressing can be minimized by reducing the grinding allowance and the severity of the operation. It should be appreciated that the frequency of dressing is always more when profiled jobs are ground, and this is unavoidable. A few specific problems that occur in precision grinding are discussed below:

Dressing: A point which should be noted is that wheel wear in dressing is substantially more than wheel wear in grinding. Most operators have a tendency to dress the wheel more than is necessary and these only results in reduced wheel life. It is recommended to remove only about 0.1 mm radial depth in dressing by taking two or three cuts of 0.02 - 0.03 mm depth after the diamond dressing tool touches the wheel throughout its width. An important aspect of the dressing operation is that it can be modified, to alter the cutting efficiency of the wheel and surface finish off the job. Thus, coarse dressing with a diamond traverse rate of 400-500 mm/min will result in a wheel with fast cutting action and a rough finish, while fine dressing with a traverse rate of 100-200 mm/min will result in a better finish. It is also possible to make a number of diamond passes at rates of 50-100 mm/min without in feed to produce a wheel-condition giving a fine finish. The latter approach is particularly useful when only a few special parts have to be made to the best surface finish in a tool room or maintenance shop. An important corollary to the above statements is that fine dressing should not be done when a free cutting wheel is required for production grinding. The influence of dressing has been discussed earlier. A typical study showed that a 46-grit cylindrical grinding wheel produced a surface finish of 30 micro inches CLA when dressed at a diamond traverse rate of 500 mm/min. Reduction of the traverse rate to 100 mm/min resulted in a 12 micro inch CLA finish.

Balancing: Proper balancing of the grinding wheel is an essential prerequisite if good results are to be obtained in precision grinding. This is because an imbalanced wheel rotating at high speeds causes severe vibrations of the spindle and leads to chatter marks on the job, damage to spindle bearings, etc. Modern machines are sometimes equipped with automatic balancing devices. However, static balancing stands are still widely used. Experience has shown that much time is lost on balancing if operators are not trained in correct balancing techniques.

Surface Finish: One of the main considerations in the choice of precision grinding processes is the required surface finish on the job. There is a widespread belief that jobs should always be ground to a very fine finish. This is totally unwarranted and can be compared to a statement that all parts should be ground to a tolerance of, say, 5microns. Such arbitrary job specifications only create difficulties during manufacture without contributing to the functional quality of the parts. The problems are further compounded by the absence of reliable evaluation methods on the shop-floor and the consequent dependence on the subjective views of the operator. It is extremely important to specify surface finishing quantitative terms, i.e., in microns R_a or micro inches CLA, so that a proper evaluation can be made on the relevant instruments at least on a sampling basis. Quite often, problems are encountered on the shop-floor in achieving the desired finish. This parameter is no doubt considered when choosing the wheel specification, but the end result is dependent on the operating conditions. The factors affecting surface finish are discussed below.